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SOME FACTORS AFFECTING HEAT AFFECTED ZONE TOUGHNESS IN TITANIUM BEARING STEELS

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SOME FACTORS AFFECTING HEAT AFFECTED ZONE TOUGHNESS IN TITANIUM BEARING STEELS

by

J.T. McGrath

ABSTRACT

The heat affected zone toughness of titanium bearing steels was studied as a function of slab cooling rate, and the levels of niobium and vanadium alloy addition. Changing the slab cooling rate from 5° to 140°C/min had little effect on the size of titanium rich precipitate particles in the as rolled steel plate. As a result no significant change in grain size and notch toughness were observed for the coarse grain heat affected zone (CGHAZ).

Reducing the level of niobium to $\leq$0.01% sharply increased the notch toughness of the CGHAZ. This improved toughness, however, was associated with a significant reduction in strength. Further tests on the effect of niobium remain to be completed.

Vanadium addition produced little change in toughness in the CGHAZ. It was further shown that 0.01% is the optimum level of titanium addition for effectively improving the toughness of the CGHAZ.

1. INTRODUCTION

It was established in the HAZ Toughness project that the addition of titanium to controlled rolled microalloy steel plate resulted in a significant improvement in the notch toughness of the heat affected zone (HAZ) of weldments, prepared by the high energy input submerged arc process (1) (2).

The promotion of a fine dispersion of stable titanium rich nitride precipitate particles controls grain growth in the coarse grain HAZ. The reduced grain size in the HAZ resulted in higher notch toughness as determined by COD and instrumented Charpy tests.

Further experimental work has been done to determine the following:

(a) The effect of slab cooling rate on the formation of titanium nitride precipitates.

(b) The effect of niobium and vanadium additions on the HAZ properties of the titanium bearing steels.

(c) The reproducibility of the results of the original experimental heats.

2. EXPERIMENTAL PROCEDURES

To study the effect of slab cooling rate on precipitate particle formation, three cooling rates were used in slab casting. The fastest cooling rate (50°-140°C/min.) was obtained by casting the heat in an iron slab mould. The intermediate rate (9°-40°C/min.) was achieved by casting in a sand mould with iron chills on two faces of the casting. Casting directly in a sand mould provided the slowest cooling rate of 5°-10°C/min. The compositions of the steels are listed in Table 1.

The effect of niobium on the HAZ properties of the titanium bearing steels was assessed over the range of niobium addition from 0 to 0.06%. The effect of vanadium was studied at two levels i.e. V = 0.05 and 0.10%. The steel compositions are contained in Table 2.

To confirm the initial results on the effect of titanium on the HAZ properties, tests were prepared with the titanium content ranging from 0 to 0.039%. Table 3 lists the compositions of these titanium steels.

In the experiments designed to study the effects of slab cooling rate and niobium and vanadium additions, the base chemistry of the tests was intended to have a titanium level of 0.01%. As noted in the chemical analyses listed in Tables 1 and 2 some of the series had to be repeated because the titanium level was lower (0.005%) than anticipated.

All heats were control rolled to 13mm gauge plate. The CGHAZ resulting from a peak temperature of 1350°C and a cooling time $\Delta t_{800°-500°C}$ = 25s was produced by simulation using the Gleeble 1500. The notch toughness of the CGHAZ was measured by the instrumented impact test. Full details of these test procedures are reported in earlier accounts of this project (1).

3. RESULTS AND DISCUSSION

3.1 Effect of Slab Cooling Rate

In determining the effect of slab cooling rate on the size and distribution of the titanium nitride precipitate particles, Godden (3) has reported that the size of titanium nitride precipitates in the as rolled steels of the 404 series was unaffected by the changes in cooling rate employed in preparing the slab cast heats. Since the control of grain growth in the CGHAZ is dependent upon the size and volume fraction of titanium nitride precipitates, the consistency in particle size has resulted in a similarity both in grain size and notch toughness of the CGHAZ of the steels of the 404 series (Table 4).

In practice, the results of the cooling rate experiment indicate that the range of cooling rates experienced in a slab during a commercial slab casting procedure are unlikely to affect the titanium particle size in the as rolled plate. These precipitates are the key to controlling grain growth and the resultant notch toughness of the CGHAZ.

3.2 The Effect of Niobium and Vanadium Additions

As shown in Table 5, reducing the niobium level of the base chemistry from 0.05 to 0.03% (heats 162 and 164) does not affect the notch toughness of the CGHAZ. As the niobium level is reduced to 0.01 and 0% there is a sharp increase in toughness. The increase in toughness, particularly in heat 168 occurred despite the relatively large grain size of the CGHAZ. The improved toughness in the niobium reduced alloys can be attributed to the lower yield and ultimate tensile strengths exhibited in the as rolled plate. For example, heat 168 (Nb = 0%) had a yield strength of 259 MPa compared to 426 MPa for heat 162 (Nb = 0.051%). Strength data was not available for the CGHAZ.

The decrease in strength with reduction in niobium level can be related to an overall decrease in volume fraction of precipitate particles. Godden's work (3) on precipitate size measurement in these steels indicated that in general there were fine titanium rich particles with a likely composition of $Ti_x \cdot Nb_{1-x} \cdot N (x \simeq 0.6)$ (4). He was not able to determine the volume fraction of the particles. If the level of niobium contributes significantly to the volume fraction of $Ti_x \cdot Nb_{1-x} \cdot N$ particles, then the number of particles would decrease as the level of niobium is reduced.

Certainly the larger grain size of the CGHAZ of heat 168 suggest fewer precipitates to control grain growth.

When the results are complete for the repeat series of niobium bearing steels (heats 453-1, 454-1, 460-1, and 449-1), more information will be available to fully determine the effect of niobium on the strength and toughness of the titanium bearing steels.

The addition of vanadium to the steels containing 0.05% niobium (heats 169 and 170) has not caused any significant changes in CGHAZ notch toughness. This can be shown by comparing the results from heats 169 and 170 with those from heat 162 in Table 5.

3.3 Reproducibility of the Effect of Titanium Addition

The toughness data from the heats repeating the original series of experimental steels confirm the effect of titanium addition as previously observed. As shown in Table 6, the addition of 0.011% titanium provides the most significant improvement in CGHAZ toughness. Higher levels of titanium (0.015 and 0.039%) are not as effective in providing higher toughness.

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Mr. M. Letts performed the Gleeble simulation experiments and Mr. R. Narraway carried out the notch toughness test program. The cooperation of the Steel Company of Canada was appreciated.

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Table 1. Chemical composition of heats designed to study the effect of slab cooling rate (wt%)

Heat	C	Mn	P	S	Si	Mo	V	Nb	ASA	N	Ti	Ti/N	Cooling (°C/min.)	Comment
160	0.066	1.86	0.002	0.006	0.23	0.28	-	0.050	0.006	0.008	0.006	0.75	50 - 140	Low Ti
272-1	0.071	1.84	0.002	0.005	NA	0.29	-	0.053	0.007	0.008	0.008	1.00	9 - 40	Low Ti
272-2	0.048	1.82	0.002	0.006	NA	0.29	-	0.054	0.006	0.010	0.008	0.80	5 - 10	Low Ti
404-1	0.075	1.80	0.002	0.004	0.29	0.31	-	0.065	0.030	0.011	0.014	1.27	50 - 140	Repeat of 160
404-2	0.070	1.79	0.002	0.005	0.29	0.30	-	0.065	0.025	0.011	0.015	1.36	9 - 40	Repeat of 272-1
404-3	0.075	1.77	0.002	0.005	0.29	0.30	-	0.060	0.025	0.011	0.015	1.36	5 - 10	Repeat of 272-2

Table 2. Chemical composition of heats to investigate the effect of niobium and vanadium alloy additions (wt%)

Heat	C	Mn	P	S	Si	Mo	V	Nb	ASA	N	Ti	Ti/N	Comment
162	0.074	1.94	0.002	0.004	0.19	0.28	-	0.051	0.008	0.008	0.005	0.63	Low Ti
164	0.069	1.98	0.002	0.004	0.23	0.28	-	0.032	0.006	0.009	0.006	0.67	Low Ti
165	0.058	1.96	0.002	0.005	0.23	0.28	-	0.009	0.011	0.009	0.005	0.56	Low Ti
168	0.044	1.99	0.002	0.005	0.21	0.26	-	-	NA	0.007	0.005	0.71	Low Ti
169	0.07	1.96	0.003	0.005	0.27	0.24	0.05	0.055	0.02	NA	0.01	NA	Effect of V
170	0.07	1.90	0.002	0.003	0.28	0.23	0.10	0.050	0.03	NA	0.01	NA	Effect of V
453-1	0.065	1.74	0.003	0.004	0.24	0.32	-	0.060	0.030	0.006	0.010	1.67	Repeat of 162
454-1	0.075	1.85	0.003	0.003	0.23	0.31	-	0.040	0.020	0.006	0.010	1.67	Repeat of 164
460-1	0.075	1.78	0.003	0.003	0.22	0.31	-	0.010	0.028	0.006	0.010	1.67	Repeat of 165
449-1	0.070	1.80	0.003	0.004	0.23	0.31	-	-	0.025	0.006	0.011	1.93	Repeat of 168

Table 3. Chemical composition of titanium bearing heats wt%

Heat	C	Mn	P	S	Si	Mo	Nb	ASA	N	Ti
233-1	0.054	1.95	0.002	0.005	0.29	0.30	0.055	0.011	0.005	-
15-2	0.056	2.04	0.002	0.006	0.26	0.29	0.056	0.019	0.013	-
233-2	0.053	1.94	0.002	0.006	0.28	0.30	0.055	0.088	0.005	0.011
404-2	0.070	1.79	0.002	0.005	0.29	0.30	0.065	0.025	0.011	0.015
11890	0.051	1.99	0.002	0.005	0.26	0.26	0.052	0.035	0.015	0.039

Table 4. Notch toughness of CGHAZ (effect of slab cooling rate)

Heat	Cooling Rate °C/min.	Austenite Grain Size (μm)	Fracture Energy J/cm^2			
			-4°C	-10°C	-18°C	25°C
160	50 - 140	68 - 79	25.7 24.8		19.3 13.3	
162	9 - 40	52 - 78	19.4 21.6		15.2 14.3	
404-1	50 - 140	26 - 34		19.4 22.0 23.3		29.0 43.0 53.0
404-2	9 - 40	34 - 40	-	18.6 17.0 18.0		31.0 36.0 41.0
404-3	5 - 10	34-40		19.1 17.7 17.0		43.0 37.0 43.0

Table 5. Notch toughness of CGHAZ (effect of Nb and V additions)

Heat	Nb	V	Austenite Grain Size (μm)	Fracture Energy J/cm^2	
				-4°C	-18°C
162	0.051	-	52 - 78	19.4	15.2
				21.6	14.3
164	0.032	-	75 - 79	20.3	8.8
				19.1	10.8
165	0.009	-	50 - 51	33.3	20.0
				32.4	12.7
168	-	-	68 - 116	43.1	35.4
				61.8	29.9
169	0.055	0.05	50 - 54	21.1	14.6
				29.1	17.2
170	0.050	0.10	47 - 56	19.1	13.3
				21.5	10.6

Table 6. Notch toughness of CGHAZ
(effect of titanium additions)

Heat	Ti	N	Austenite Grain Size (μm)	Fracture Energy J/cm^2	
				-10°C	25°C
233-1	-	0.005	94 - 125	11.2	35.0
				9.4	28.0
				12.3	46.0
15-2	-	0.013	68 - 95	14.9	47.0
				13.8	41.0
					42.0
233-2	0.011	0.005	40 - 68	18.2	50.0
				32.9	55.0
				35.5	60.0
404-2	0.015	0.011	34 - 40	18.6	31.0
				17.0	36.0
				18.0	41.0
11890	0.039	0.015	40 - 58	14.9	33.0
				12.5	39.0
				13.1	25.0